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RESEARCH PAPER

Soil structure characters of different soil and water conservation plantations in typical black soil region

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Abstract: A study was conducted to determine the characters of soil structure in different water and soil conservation forests in Keshan County, northwest of Heilongjiang Province, China. The soil bulk density, the ratio of non-capillary porosity and capillary porosity (NCP/CP), and the generalized soil structure index (GSSI) were measured for *Fraxinus mandshurica*, *Larix gmelini*, *Pinus sylvestris* var. *mongolica*, and *Picea koraiensis* plantations as well as the abandoned land (as control) adjacent to the forests in typical black soil region. Results show that at soil depth of 0–30cm, the soil bulk density of *F. mandshurica* forest and *L. gmelini* forest was lower than that of *P. sylvestris* var. *mongolica* forest and *P. koraiensis* forest, with the relative decrease of 8.04%–11.01%. The soil bulk density of *L. gmelini* forest was significantly different from that of the *P. sylvestris* var. *mongolica* forest and *P. koraiensis* forest. The NCP/CP values of the four types of plantations were all higher (59.75%–128.82% relatively) than that of abandoned land (p<0.05), indicating that the soil aeration and permeability under forest were enhanced, especially under *L. gmelini* forest. GSSI values of the four types of forests were also relatively higher (2.98%–4.36%) than abandoned land (p<0.05)，indicating that those soil and water conservation forests, especially the *F. mandshurica* forest and *P. koraiensis* forest, can promote soil condition to approximate ideal soil structure. The result of this study can provide theoretical basis for scientifically evaluating the effects of vegetation restoration on soil quality in typical black soil region.

Keywords: typical black soil; soil and water conservation plantation; Bulk density; GSSI; NCP/CP

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Introduction

Soil structure is one most important indicator of soil quality (Karlen 1997; Zhou 2009), which could be influenced by natural environmental change and all kinds of human activities, and has extremely important significance in evaluating soil degradation and recovery process. It is definitely true that soil process and function depend on soil structure (Liu 2002). Soil structure could influence fertility condition and soil water availability for root growth, subsequently yield and quality of crop. It is also a critical factor to affect soil strength, infiltration and water flow. Thus, researches relative to soil structure would succeed in understanding and evaluating soil erodibility (Zeng 1995).

Typical black soil region is located in the central area of China for cereal grain production. The soil erosion and ecological frangibility is increasingly serious (Luo 1995) in this area because of unreasonable reclamation of black soil resource and natural vulnerability (Xu 2006). The positive effects of soil and water conservation forests on soil properties have been adequately discussed (Shi 2009). Soil and water conservation forests could weaken soil erosion and reduce soil loss through adjusting allocation of precipitation and also can improve soil structure and enhance soil anti-erodibility through increasing soil organic matter content by litter decomposition (Prescott 2005). The objective of this study was to determine the effects of different soil and water conservation forests on soil structure by measuring and analyzing soil bulk density, the ratio of non-capillary porosity and capillary porosity (NCP/CP), and generalized soil structure index (GSSI). We expect to scientifically evaluate recovery and reconstruction of water and soil conservation forests in typical black soil region with results of this research.

Materials and methods

Study area

The study area was located in Keshan Farm in Keshan County, northwest of Heilongjiang Province, China (latitude

48°12′–48°23′N, longitude 125°8′–125°37′E), with elevation of 240–340 m a.s.l. and an average slope of 3°. The main soil, *Luvic Phaeozems*, was classified as typical black soil (Gong 1999). Keshan County is temperate continental monsoon climate, with the mean annual precipitation of 501.7 mm, mean temperature of 0.9ºC, effective accumulated temperature (≥10ºC) of 2296.2ºC, average evaporation of 1329.4 mm, and frost-free period of 115 days per year.

Sampling methods

Four 20 m × 20 m plots were separately set for plantations of *Fraxinus mandshurica, Larix gmelini, Pinus sylvestris* var. *mongolica* and *Picea koraiensis*. Those stands have relatively uniform site conditions, growth stage and management practices. Meanwhile, a 20 m×20 m plot of abandoned land adjacent to the stands was selected as control (Table 1).

Three composite soil samples were collected at depth of 0–10 and 10–30 cm (Wu 2008) from *F. mandshurica* forest, *L. gmelini* forest, *P. sylvestris* var. *mongolica* forest, *P. koraiensis* forest and abandoned land to provide an adequate representation of site heterogeneity. Each composite sample is a mixtue of soil from three randomly selected locations within each of the 20 m×20 m plots. The soil bulk density and porosity were measured at the depth of 0–10, 10–30 cm based on the method of core sampler (100 cm^3), and the NCP/CP and GSSI of topsoil (0–10 cm) and subsoil (11–30 cm) were calculated respectively (Wang 2007, 2009).

Table 1. Stand characteristics in the experimental fields in Keshan Farm in Keshan County, northwest of Heilongjiang Province, China

Forest types	Altitude (m)	Gradients (°)	Aspect	Age (a)	BDH (cm)	Tree height (m)	Canopy closure	Density (No./ ha)
Abandoned land	302	2	NW	-	-	-	-	-
F. mandshurica forest	294	7	NW	42	15.54	22.5	0.6	875
L. gmelini forest	315	5	NW	45	16.77	15.8	0.6	650
P. sylvestris var. *mongolica* forest	302	3	NW	46	20.55	13.5	0.5	775
P. koraiensis forest	300	5	NW	42	7.96	8.3	0.5	975

Data analysis

The t-test was used to compare the differences between abandoned land and the plantations. The results were considered significant when $p < 0.05$. The analyses were performed using SPSS 13.0 GLM.

Result and analysis

Soil bulk density

The average soil bulk density in four types of plantation was 1.87%–13.08% relatively higher than that in abandoned land (Table 2). This may be due primarily to the fact that surface vegetation can affect the soil humus transform process by means of changing the litter composition. As a result, the humus transform rate was higher in abandoned land than in forests because the abandoned land was covered mainly with herbaceous plants. Secondly, this might be due to the fact that plenty of sunshine and water can activate the soil microbial components by increasing the soil organic matter content and loosening soil structure. Soil bulk density under *L. gmelini* forest was significantly different from which under *P. sylvestris* var. *mongolica* forest and *P. koraiensis* forest; and the difference of soil bulk density was also statistically significant between *F. mandshurica* forest and *P. koraiensis* forest ($p<0.05$).

Soil bulk density increased with increasing depth of soil in abandoned land, but it was not the same case for all the plantations (Table 2). This trend was also evident in the *F. mandshurica* forest and *P. koraiensis* forest, but a contrary trend was observed in the *P. sylvestris* var. *mongolica* forest; however no significant difference was observed in soil bulk density in soil profile in *L. gmelini* forest. The contrary result observed in *P. sylvestris* var. *mongolica* forest is possibly due to the fact that the litter layer was collected by farmers for burning warm and/or soil was compacted by trample. The average bulk density is in the order of *L. gmelini* forest < *F. mandshurica* forest < *P. sylvestris* var. *mongolica* forest < *P. koraiensis* forest. Overall, both *L. gmelini* forest and *F. mandshurica* forest played an important role in loosening soil and decreasing soil bulk density. In *F. mandshurica* forest, the soil bulk density of topsoil was lower than that of subsoil because of higher rate of litter decomposition and humus transforming (Shen 2000).

Table 2. Soil bulk density in different sample plots

Forest type	Soil bulk density (g·cm^{-3})		
	0–10cm	11–30 cm	Average
Abandoned land	1.02 ± 0.12 a	1.10 ± 0.04 a	1.07 ± 0.07 a
F. mandshurica forest	1.04 ± 0.06 a	1.16 ± 0.09 b	1.12 ± 0.09 ab
L. gmelini forest	1.11 ± 0.18 a	1.08 ± 0.04 a	1.09± 0.09 a
P. sylvestris var. *mongolica*	1.25 ± 0.07 b	1.11± 0.09 ab	1.16 ± 0.08 bc
P. koraiensis forest	1.11± 0.09 a	1.26 ± 0.08 c	1.21 ± 0.08 c

The "±"means standard deviation. Different letters in same column mean significant difference ($p<0.05$).

NCP/CP

The ratio of non-capillary porosity and capillary porosity of soil were used to represent the soil aeration, soil permeability and soil water holding capacity (Qiu 1998). The higher value of NCP/CP not only means reducing ground runoff, lessening water loss and weakening soil erosion threat because of increasing infiltration capacity, but also means lowering soil evaporation and improving soil gas exchange (Wang 2008). In this study we found that the values of NCP/CP in plantations were all higher than that in abandoned land ($p<0.05$), with the average relative increase of

59.75%–128.22% (Fig. 1), demonstrating that forest could improve the quality of soil structure. The average value of NCP/CP was in order of *L. gmelini* forest (0.110) > *P. koraiensis* forest (0.103) > *F. mandshurica* forest (0.082) > *P. sylvestris* var. *mongolica* forest (0.077), it could be drawn that the soil under *L. gmelini* forest had best structure condition among the four types of plantations.

The value of NCP/CP obviously decreased with increase of soil depth in abandoned land. The reasonable interpretation for this phenomenon is that the roots of herbaceous plants existed in topsoil could affect soil porosity significantly, but it was not the case for other plantations. Values of the NCP/CP under the *F. mandshurica* forest and *P. sylvestris* var. *mongolica* forest increased slightly from topsoil to subsoil. A sharp increase (177.84%) of NCP/CP was observed from topsoil to subsoil under *L. gmelini* forest（$p<0.05$）. However, the value of NCP/CP had a significant decrease (196.26%) from topsoil to subsoil under *P. koraiensis* forest. This may be derived from that loosen action of root system on soil aeration by making soil porosity larger and soil particle realignment (Gill 2000). It also indicated that plantations with shallow root system had greater influence on the value of NCP/CP in topsoil than that in subsoil.

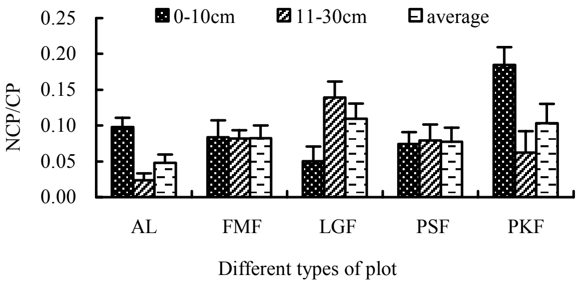

Fig. 1 NCP/CP in different sample plots

Notes: AL---Abandoned land, MAF---*F. mandshurica* forest, LGF---*L. gmelini* forest, PSF---*P. sylvestris* var. *mongolica* forest, PKF--- *P. koraiensis* forest.

GSSI

Soil structure is defined as the arrangement and combination in three dimensions of soil primary particles and soil secondary particles, which is a semi-infinite medium composed up by solid, liquid and gas phases. The change of soil structure based upon soil three phases could be quantified by generalized soil structure index (GSSI) (Wang 2009). The average value of GSSI was 2.98%–4.36% higher ($p<0.05$) in plantations than that in abandoned land relatively (Fig. 2), indicating that plantation has more contribution to improving soil structure. GSSI increased with increasing depth of soil in abandoned land; however the GSSI in different soil depths was lower than corresponding value under four plantations.

Among the four plantations, soil in *F. mandshurica* forest has the highest value of GSSI (97.00), followed by *P. koraiensis* forest (96.45) and *L. gmelini* forest (94.75) successively, and the lowest GSSI (94.64) was observed in *P. sylvestris* var. *mongolica* forest. The GSSI of *F. mandshurica* forest was significantly different from *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest ($p<0.05$). It could be concluded that the *F. mandshurica* forest have strongest capacity in improving soil structure. The GSSI increased with increasing depth of soil in *F. mandshurica* forest and *P. koraiensis* forest, and the variation of GSSI for *F. mandshurica* forest was in range of 94.13–98.44. It indicated that soil structure at 0–30cm in *F. mandshurica* forest was in good condition. However, GSSI changed dramatically in different soil depths of *P. koraiensis* forest, 9.54% higher in subsoil than in topsoil, which is related to the distribution of root system of Korean spruce, that is, the roots of this tree species distributes mainly in topsoil while little distributed in subsoil (Hu 2004). In *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest, GSSI decreased with increase of soil depth and no significant change of GSSI was observed between *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest.

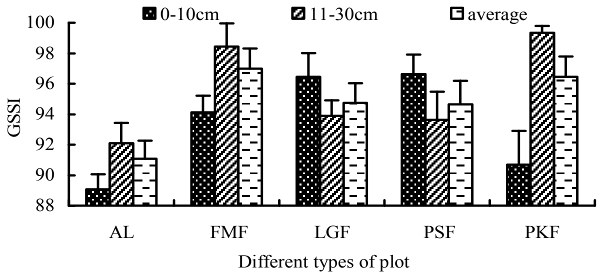

Fig. 2 Results of GSSI in different sample plots

Notes: AL---Abandoned land, MAF---*F. mandshurica* forest, LGF---*L. gmelini* forest, PSF---*P. sylvestris* var. *mongolica* forest, PKF--- *P. koraiensis* forest.

Different types of soil and water conservation plantations have different levels of contributions to improving soil structure. Soil microorganism and soil fauna that can change soil structure directly were affected by the form and quantity of soil organic matter from different plantation litters. Furthermore, growth of plant roots played an important role in transforming soil structure.

Solid, liquid and gas components of soil and the variation of proportion could be reflected directly in soil two-dimension and three-phase diagram. Combined with analyses based on Fig. 2, the soil structure of *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest were closer to ideal structure compared to abandoned land and other plantations within topsoil (0–10cm) (Fig. 3). Compared with abandoned land and *F. mandshurica* forest, the soil structure of *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest approached to ideal structure through reducing the proportion of gas and increasing the proportion of liquid and solid, while compared with *P. koraiensis* forest, the soil structure of *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest moved forward to ideal structure by reducing the proportion of gas and increasing the proportion of liquid. Soil structures of *F. mandshurica* forest and *P. koraiensis* forest within subsoil (11–30cm) were more ideal than those of abandoned land and other plantations. Compared with abandoned land, the soil structure of *F. mandshurica* forest and *P. koraiensis* forest accessed to ideal structure through decreasing the proportion of liquid and increasing the proportion of gas and solid, while compared with *P. sylvestris* var. *mongolica* forest and *L. gmelini* forest, the soil structures of *F. mandshurica* forest and *P. koraiensis* forest came to ideal structure by diminishing the proportion of gas and improving the proportion of solid. These results were in

agreement with the previous analyses on NCP/CP and GSSI. In conclusion, soil structure is an integrated system made up of three phases, and it could not be improved well only by changing any single phase.

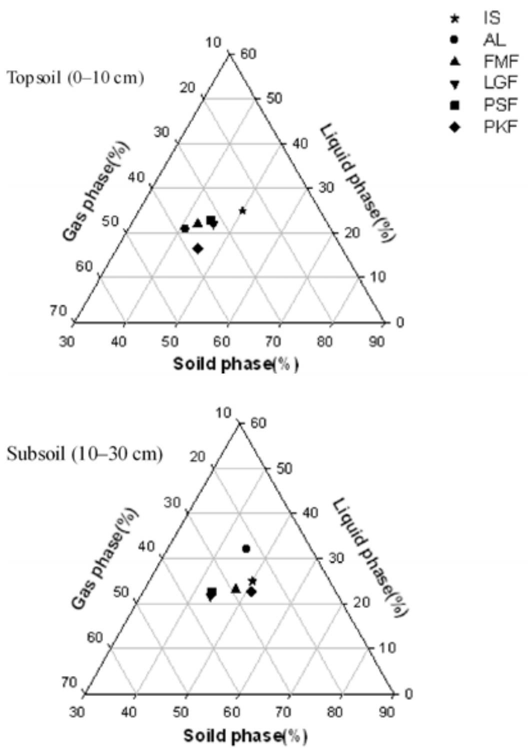

Fig. 3 Change of soil three phases in different plots

Notes: IS, AL, FMF, LGF, PSF and PKF means Ideal structure, Abandoned land, *F. mandshurica* forest, *L. gmelini* forest, *P. sylvestris* var. *mongolica* forest and *P. koraiensis* forest, respectively.

Conclusion

L. gmelini forest and *F. mandshurica* forest have relatively great effects on reducing soil bulk density, loosening soil, and improving soil structure at 0–30cm depth. *F. mandshurica* forest plays a significant role in decreasing soil bulk density in topsoil because of higher rate of litter decomposition and humus transforming.

The ratio of non-capillary porosity/capillary porosity (NCP/CP) within soil of 0–30 cm depth in four plantations were all higher than that in abandoned land (p<0.05), indicating that plantations could improve the quality of soil structure. *L. gmelini* forest had highest value of NCP/CP, indicating that the soil of *L. gmelini* forest had comparative better porous structure.

Combined with GSSI analyses and changes of soil three phases in soil two-dimension and three-phase diagram, the soil structure of *L. gmelini* forest and *P. sylvestris* var. *mongolica* forest were closer to ideal structure than that in abandoned land and other plantations within topsoil (0–10 cm). Soil structures of *F. mandshurica* forest and *P. koraiensis* forest were nearer to ideal structure compared to abandoned land and other plantation within subsoil (11–30 cm). They were caused by different processes of phase changing.

Based on the integrated analyses of soil bulk density, NCP/CP, GSSI and change of soil three phases in soil two-dimension and three-phase diagram, it could be concluded that in typical black soil region, soil and water conservation plantations could improve soil structure. Furthermore, *F. mandshurica* forest and *P. koraiensis* forest had more significant effects on improving soil structure compared to the other plantations.

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